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AN EMPIRICAL MODEL OF THE VERTICAL STRUCTURE OF GERMAN FOGS

NOVEMBER 1980

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Data available from balloon-borne measurements of fog particle size distributions were analyzed to develop an empirical model of the vertical structure of German fogs. The data base consisted of approximately two dozen profiles collected at Grafenwöhr and Meppen, Germany. Curve fitting procedures were applied to the results of liquid water content calculations and extinction coefficients calculations to develop single algorithms. Tables are included to show comparisons of the model outputs with the original data.

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CONTENTS

INTRODUCTION

United States and North Atlantic Treaty Organization (NATO) military forces are increasingly relying on new sophisticated weapons and surveillance systems which incorporate electro-optical (E-O) sensors. Since many of these systems can be strongly influenced by the atmospheric environmnent, these atmospheric conditions must be understood and models must be developed which permit assessment through simulation of the actual performance.

In the past few years numerous data have been gathered on the optical properties and microphysical characteristics of fog at various locations such as Grafenwöhr, Meppen, and Baumholder in West Germany and the NATO project OPAQUE (optical atmospheric quantities in Europe) stations in Europe. Supplemental data have come from various United States locations, notably Fort AP Hill in Virginia. With a few exceptions, all of these data were obtained along horizontal propagation paths. However, observations often show that there are circumstances in fog conditions when the density of the fog near ground level is not representative of conditions even a few tens of meters above the surface. This difference in density implies that slant path transmission can be significantly different from horizontal transmission at the surface.

The purposes of this report are to describe an empirical model which has been developed to describe the vertical variation of the density of fogs in central Europe, discuss some of the rationale behind the model, and point out that serious inadequacies in the data base have permitted an algorithm of limited applicability to be developed at this time.

DATA BASE

As mentioned above, there are a few exceptions to the statement that the existing data base consists of ground observations. These exceptions are several sets of measurements of fog droplet size distributions at different altitudes obtained with the use of balloon-borne particulate spectrometers. Measurements have been made on a few selected occasions in wintertime fog in Grafenwöhr and Meppen, Germany, and in April at Fort Ord, California. The Grafenwöhr data are described in an Atmospheric Sciences Laboratory (ASL) data report,[1] and curves of calculated extinction and liquid water content (LWC) based on these measurements have been published.[2] The Meppen measurements are not yet published, but the data from Fort Ord have been.[3] None of these

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[1]D. L. Hoihjelle et al, 1976, Balloon-borne Aerosol Particle Counter Measurement Mode in Wintertime at Grafenwohr, West Germany, Data Report ECOM-DR-76-3, Atmospheric Sciences Laboratory, White Sands Missile Range, NM

[2]R. G. Pinnick et al, 1978, Vertical Structure in Atmospheric Fog and Haze and Its Effect on IR Extinction, ASL-TR-0010, Atmospheric Sciences Laboratory, White Sands Missile Range, NM

[3]R. B. Loveland et al, 1978, Atmospheric Characterization Measurements for Copperhead Ground Fog Experiment, ASL Internal Report, Atmospheric Sciences Laboratory, White Sands Missile Range, NM

blocks of data provides any comprehensive picture of the characteristics of fog as a function of altitude, and the total data are sparse enough that any claim of statistical significance is unwarranted. However, the data do clearly show one important thing: There are occasions at each location when the number density of fog droplets increases very strongly with altitude in a steady manner. Calculations of visible and infrared extinction based on these particulate spectrometer measurements show that it is not uncommon to find an increase in extinction of two orders of magnitude in the first 300 meters above the surface. Examples of extinction and LWC profiles for this kind of fog situation are shown in figures 1 and 2.

Each of the data sets above includes data from situations where shallow ground fog is present, and at some moderate altitude the top of the fog is reached and the balloon instrumentation enters clear air. This occurrence is commonly the case with ground fog or low lying patchy radiation fog. No effort has been made so far to deal with these many inhomogeneous fogs. This report addresses the case where the fog appears uniform in horizontal extent, where it has not been changing rapidly in time, and where the visibility on the ground is in the range from a few tens of meters to 3 kilometers.

DISCUSSION

One way of incorporating into a model a description of a fog such as that represented by the extinction calculations shown in figure 1 would be to assume that the logarithms of the extinction coefficient, LWC, increase linearly with altitude from some value at the surface and that the gradient (the increase in LWC with increase in altitude) is such that a change of two or three orders of magnitude can occur over a vertical distance of about 250 meters. Use of this assumption results in a profile which is a coarse approximation of some of the measured results. However, examination of profiles such as those shown in figures 1 and 2 shows that the gradient is not constant and, in fact, appears to change with LWC. For the class of fogs being discussed here, the assumption that the rate of change of extinction coefficient or LWC as a function of altitude is directly related to LWC leads to an algorithm which produces a better description of the existing measured data than does a straight linear profile approximation.

The physical basis for such an assumption can be examined. Measured data show that there are cases when the visibility on the ground is on the order of a few kilometers and that the vertical gradient is large; that is, the LWC increases rapidly with altitude so that at an altitude of 200 or 300 meters the visibility may be as low as a few tens of meters. This kind of phenomenon has been measured and is in the existing data base. If an extreme situation is examined where the LWC at the ground is extremely high (perhaps approaching 1 gram per cubic meter), the increase with altitude is not so great. The microphysics of fog droplets impose limitations that establish an upper bound on the LWC. When the fog at ground level has a density approaching this limit (when the ground visibility is a few tens of meters), then a major increase with altitude cannot be expected. In the other extreme case where LWC is low, haze conditions are being approached; and in a light haze, such strong vertical density gradients do not occur.

DEVELOPMENT OF THE ALGORITHM

The measured fog droplet size distributions were used to compute extinction coefficients at three wavelengths (0.55, 4.0, and 10 micrometers). These coefficients, together with computed LWC, are given at 20-meter-altitude increments in tables 1 through 18 (under the columns labeled MEAS) for the 18 profiles used in the development of the algorithm. Because of the limitations in the existing data base, a decision was made to develop an empirical algorithm which could be used to model these profiles. Such a model, however, can be considered valid only to the extent that it is able to represent these data.

When various procedures for developing the algorithm were being investigated, the first question to be answered was how the algorithm should function. The criteria established were that it should accept either LWC or extinction coefficient at the surface as a basic input and provide values of the variable at a desired altitude above the surface as the basic result. Four different metrics for fog density were investigated. These metrics were extinction coefficients at 0.55, 4.0, and 10 micrometers in units of kilometers^{-1} and LWC in grams per cubic meter.

Early in the analysis of the data, it became apparent that the increase in fog density (as measured by any of these four metrics) through a layer of given thickness depended primarily upon the value of fog density itself. With this in mind, various procedures for expressing this change in fog density were investigated. The investigation showed that the function

$$y = ax + b, \tag{1}$$

where $x = \log D(z)$, $y = \log D(z + 20)$, and a and b are coefficients, provided a good fit to the available data. In this equation, $D(z)$ is the value of the fog density at altitude z, and $D(z + 20)$ is the corresponding value at altitude z + 20 meters. The fit of equation (1) to the data is shown in figures 3, 4, 5, and 6 for the fog density metrics extinction coefficient at 0.55, 4.0, and 10 micrometers, and LWC, respectively. When these graphs were being prepared, intervals of width 0.25 in x were chosen (that is, a factor of 1.78 change in the fog density metric), and the mean values of x and y were computed and plotted for each interval. The vertical lines through the points depict one standard deviation in y. The two straight lines shown in each figure were "eyeball" fit to the data points.

A comparison of the equations obtained from the data shown in figures 3 through 6 reveals that the fitted lines for the different metrics are nearly parallel. This near parallelism suggests that the four metrics for fog density have about equal utility for describing the vertical structure of these fogs. Therefore, it is not important whether extinction at some particular wavelength or LWC is chosen as the metric D(z) for use in the model.

COMPARISON OF MEASURED AND MODELED FOG DENSITY

The sets of equations shown in figures 3 through 6 were used to model the observed fog profiles. The point of intersection of the two lines was used to determine which equation was applicable for a given calculation. (Note that for a given metric either one or both of the equations may be required for a simulated profile.) A profile is computed in a sequential process. The value of D(z) at the surface is used to obtain the value of D(z) at 20 meters; this value is then used to compute the value at 40 meters, and so on. The procedure was applied to each of the measured profiles. The results are shown in tables 1 through 18 under the column labeled MOD. A comparison of the measured and modeled values indicates excellent agreement in over half of the profiles with reasonable agreement for the others, with the exception of the profiles shown in tables 3 and 10. A closer inspection of these results reveals that when $K_{0.55}$ is used as the metric for fog density 57 percent of the time the difference between the measured and modeled value is within 25 percent of the measured value, while this difference is greater than the measured value for only 17 percent of the comparisons.

CONCLUSIONS AND RECOMMENDATIONS

The model presented herein is based upon measurements from a balloon-borne spectrometer. Since data above about 250 meters altitude were not available, the validity of the model above this altitude is unknown. In addition, the model is not applicable for patchy ground fog or horizontally inhomogeneous fogs.

Since the model has been developed from a limited data base of unknown statistical significance, the general applicability of the algorithms is unknown. However, the model does provide a representation of fog profiles which have been encountered in Germany on many occasions and, therefore, must be contended with in systems performance analysis. Moreover, the use of this model does not, in any case, lead to a result that is unreal or too extreme to be reasonably expected. What is lacking is any real sense of probability of occurrence of such fogs, extension of the model to higher altitudes, and similar algorithms to account for the shallow ground fog case. The ASL plans to obtain additional data from future field measurement programs to obtain a better understanding of this important problem area.

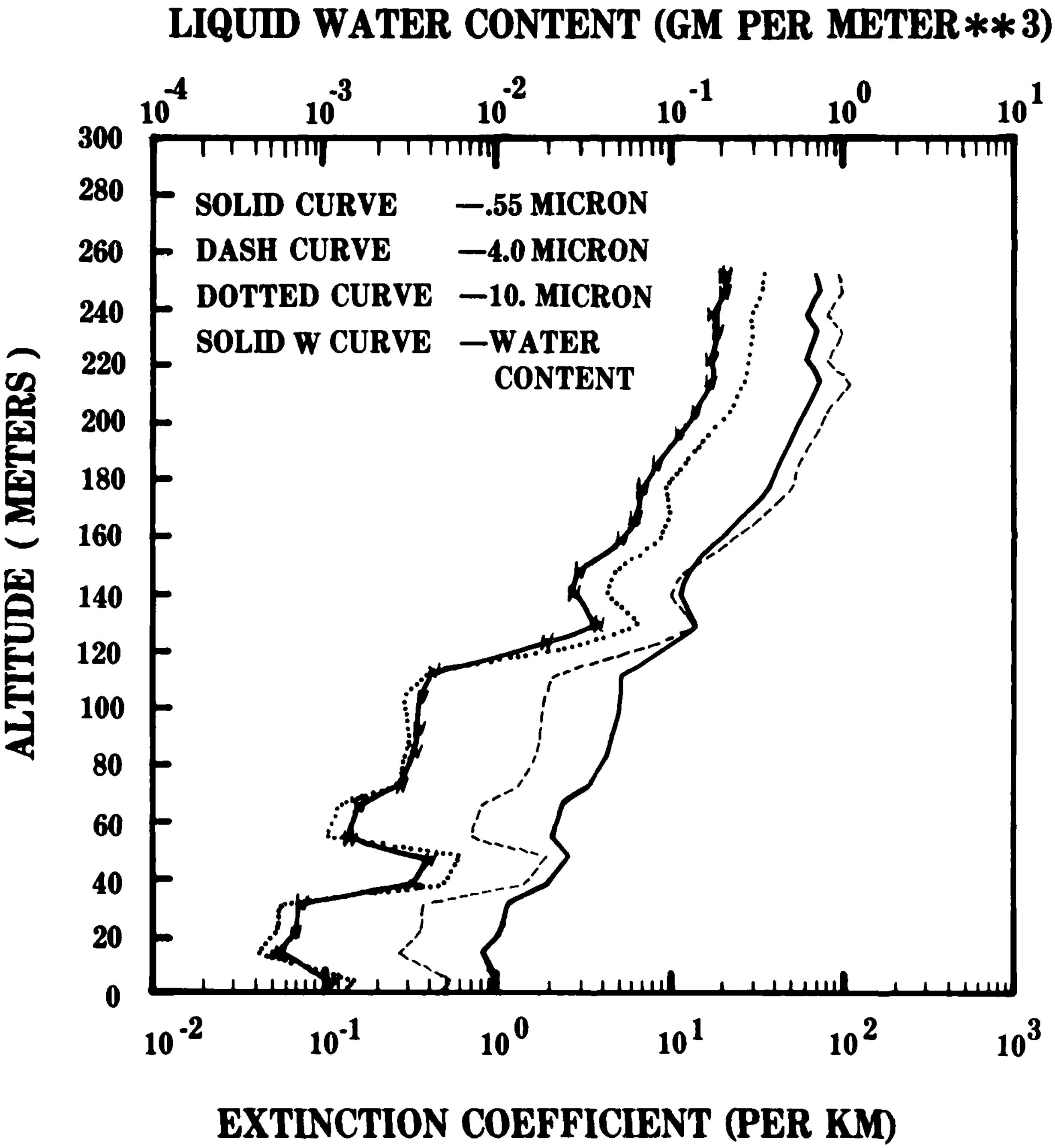

Figure 1. Vertical profile measured at Grafenwöhr, GE, on 22 Feb 76 (from reference 2).

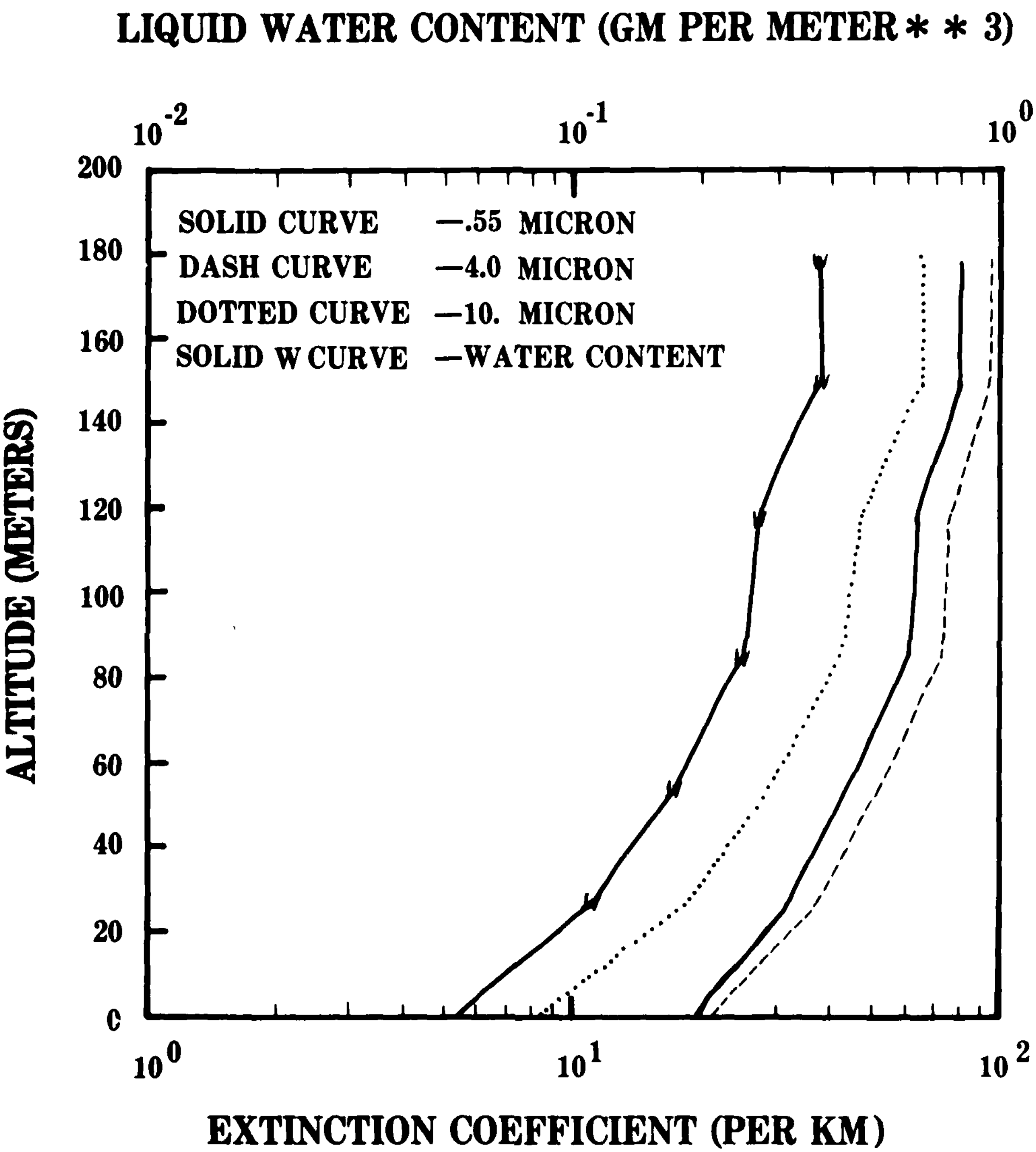

Figure 2. Vertical profile measured at Grafenwöhr, GE, on 25 Feb 76 (from reference 2).

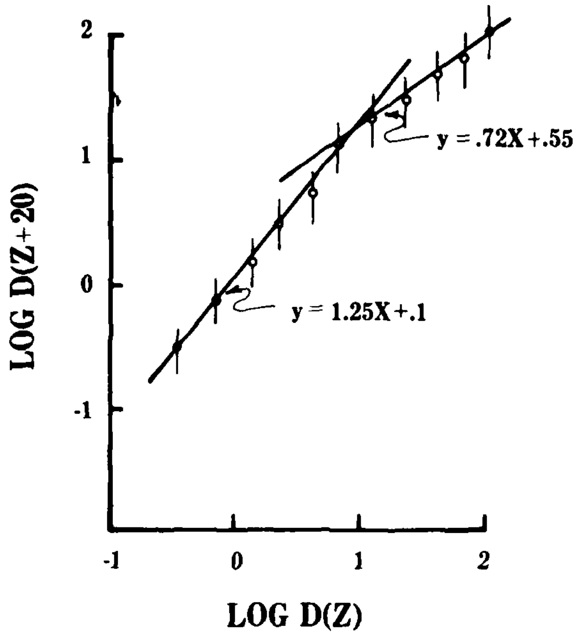

Figure 3. Relationship between fog density metric at altitudes z and z + 20 meters. Extinction coefficient at 0.55 micrometer used as fog density metric. D(z).

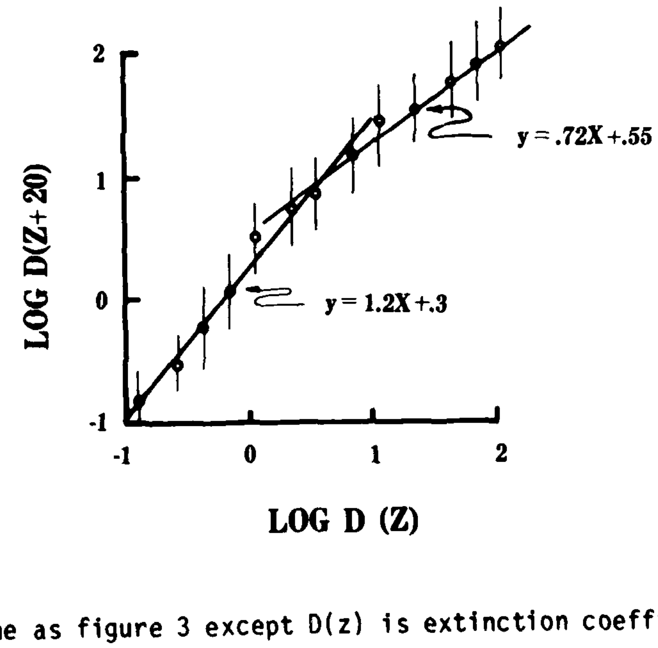

Figure 4. Same as figure 3 except D(z) is extinction coefficient at 4.0 micrometers.

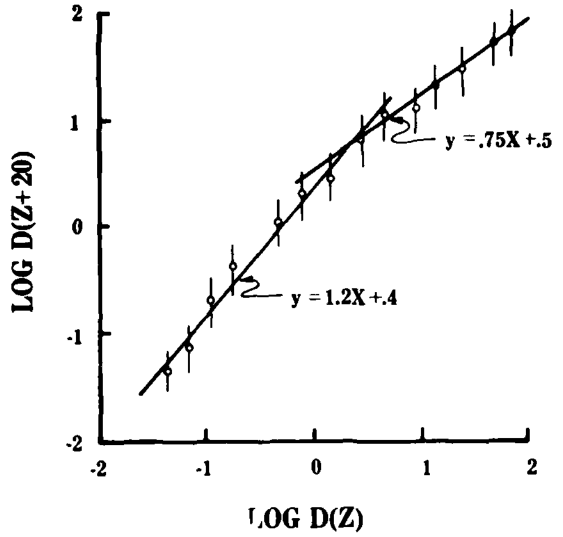

Figure 5. Same as figure 3 except D(z) is extinction coefficient at 10.6 micrometers.

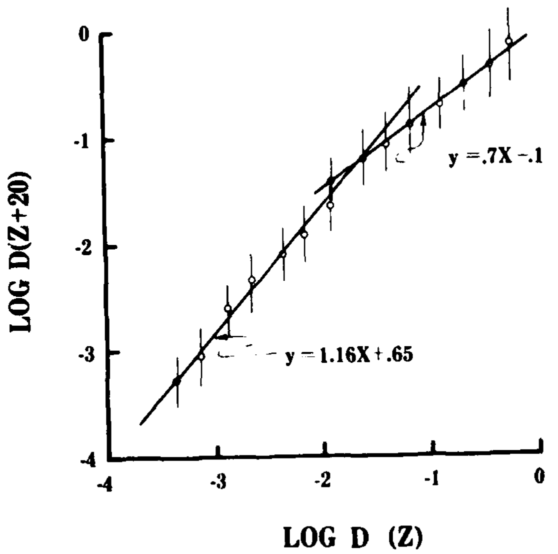

Figure 6. Same as figure 3 except D(z) is liquid water content.

TABLE 1. COMPARISON OF MEASURED AND MODELED PROFILES 21 FEB 76 0957

ALT	K .55		K 4.0		K 10.6		LWC	
M	MEAS	MOD	MEAS	MOD	MEAS	MOD	MEAS	MOD
0	1.32	1.32	0.48	0.48	0.07	0.07	0.0009	0.0009
20	1.43	1.78	0.54	0.83	0.10	0.14	0.0011	0.0013
40	2.57	2.59	1.15	1.59	0.20	0.28	0.0022	0.0020
60	5.42	4.14	2.93	3.48	0.65	0.58	0.0066	0.0033
80	14.25	7.43	13.71	8.90	4.52	1.27	0.0304	0.0060
100	29.10	15.44	35.25	17.12	13.95	2.88	0.0830	0.0118
120	45.32	25.46	56.83	27.43	24.28	7.00	0.1575	0.0260
140	63.10	36.49	77.62	38.50	31.62	13.61	0.2512	0.0617

TABLE 2. COMPARISON OF MEASURED AND MODELED PROFILES 21 FEB 76 1039

ALT	K .55		K 4.0		K 10.6		LWC	
M	MEAS	MOD	MEAS	MOD	MEAS	MOD	MEAS	MOD
0	1.51	1.51	0.52	0.52	0.08	0.08	0.0010	0.0010
20	1.98	2.11	0.73	0.91	0.10	0.16	0.0014	0.0015
40	3.04	3.20	1.20	1.78	0.17	0.32	0.0022	0.0023
60	6.31	5.38	3.49	3.99	1.30	0.68	0.0094	0.0039
80	13.27	10.32	10.05	9.61	5.45	1.50	0.0327	0.0076
100	22.87	19.04	21.30	18.10	13.27	3.42	0.0739	0.0148
120	33.11	29.61	35.48	28.55	23.43	7.95	0.1259	0.0336

TABLE 3. COMPARISON OF MEASURED AND MODELED PROFILES 23 FEB 76 1718

ALT	K .55		K 4.0		K 10.6		LWC	
M	MEAS	MOD	MEAS	MOD	MEAS	MOD	MEAS	MOD
0	1.00	1.00	0.09	0.09	0.02	0.02	0.0003	0.0003
20	1.00	1.26	0.09	0.11	0.04	0.04	0.0003	0.0004
40	1.03	1.68	0.10	0.14	0.03	0.07	0.0003	0.0005
60	1.10	2.41	0.11	0.19	0.02	0.14	0.0004	0.0006
80	1.19	3.77	0.13	0.28	0.02	0.28	0.0004	0.0088
100	1.31	6.62	0.15	0.43	0.03	0.58	0.0006	0.0012
120	1.52	13.36	0.21	0.72	0.04	1.27	0.0006	0.0018
140	1.92	22.94	0.35	1.34	0.06	2.88	0.0008	0.0029
160	2.82	33.86	0.60	2.84	0.11	6.99	0.0020	0.0051
180	6.16	44.81	2.44	6.98	0.36	13.59	0.0040	0.0098
200	15.02	54.82	9.46	14.37	1.28	22.38	0.0057	0.0208
220	24.07	63.40	17.99	24.18	2.35	32.54	0.0073	0.0528
240	25.12	70.39	22.39	35.16	2.51	43.09	0.0282	0.1013

TABLE 4. COMPARISON OF MEASURED AND MODELED PROFILES 25 FEB 76 0729

ALT	K .55		K 4.0		K 10.6		LWC	
M	MEAS	MOD	MEAS	MOD	MEAS	MOD	MEAS	MOD
0	22.39	22.39	24.45	24.45	10.47	10.47	0.0631	0.0631
20	28.47	33.27	32.28	35.45	15.32	18.41	0.0924	0.1148
40	37.74	44.25	44.29	46.31	23.14	28.10	0.1395	0.1746
60	47.61	54.33	56.98	56.14	31.49	38.60	0.1884	0.2341
80	57.27	62.98	68.42	64.49	38.97	48.97	0.2353	0.2876
100	63.52	70.05	75.48	71.26	43.45	58.54	0.2681	0.3316
120	68.14	75.63	81.48	76.57	48.91	66.92	0.2984	0.3670
140	74.76	79.92	88.79	80.63	58.51	73.99	0.3407	0.3938
160	80.40	83.16	93.33	83.69	64.96	79.78	0.3695	0.4137
180	83.18	85.57	95.50	85.97	66.07	84.41	0.3802	0.4282

TABLE 5. COMPARISON OF MEASURED AND MODELED PROFILES 25 FEB 76 1225

ALT	K.55		K 4.0		K 10.6		LWC	
M	MEAS	MOD	MEAS	MOD	MEAS	MOD	MEAS	MOD
0	11.32	11.32	10.14	10.14	5.01	5.01	0.0316	0.0316
20	18.08	20.36	20.36	18.81	8.92	10.59	0.0558	0.0768
40	28.81	31.07	35.38	29.34	16.02	18.56	0.0974	0.1244
60	39.64	42.12	48.62	40.42	25.21	28.28	0.1471	0.1847
80	51.15	52.43	62.23	50.91	34.68	38.78	0.1967	0.2435
100	61.32	61.39	74.63	60.10	42.72	49.14	0.2436	0.2955
120	65.69	68.78	78.98	67.73	49.78	58.69	0.2884	0.3384
140	66.06	74.64	77.62	73.82	56.23	67.06	0.3236	0.3720

TABLE 6. COMPARISON OF MEASURED AND MODELED PROFILES 25 FEB 76 1320

ALT	K.55		K 4.0		K 10.6		LWC	
M	MEAS	MOD	MEAS	MOD	MEAS	MOD	MEAS	MOD
0	19.33	19.33	20.17	20.17	7.41	7.41	0.0464	0.0464
20	25.58	29.93	27.88	30.86	15.83	14.20	0.0853	0.0926
40	36.94	41.00	41.99	41.91	26.62	23.14	0.1347	0.1502
60	47.85	51.43	55.11	52.25	32.42	33.86	0.1712	0.2107
80	56.18	60.54	65.66	61.24	40.89	48.89	0.2319	0.2670
100	66.03	68.09	78.88	68.65	52.73	53.93	0.3063	0.3152
120	72.45	74.10	85.12	74.54	58.73	62.93	0.3397	0.3540
140	74.13	78.75	83.18	79.09	64.53	70.65	0.3715	0.3840

TABLE 7. COMPARISON OF MEASURED AND MODELED PROFILES 25 FEB 76 1601

ALT	K.55		K 4.0		K 10.6		LWC	
M	MEAS	MOD	MEAS	MOD	MEAS	MOD	MEAS	MOD
0	33.95	33.95	39.07	39.07	17.56	17.56	0.1121	0.1121
20	43.39	44.90	50.71	49.67	24.53	27.13	0.1505	0.1717
40	53.70	54.90	62.67	59.05	33.92	37.59	0.1986	0.2314
60	64.52	63.64	73.97	66.88	44.81	48.00	0.2591	0.2851
80	76.28	70.44	87.73	73.15	55.71	57.67	0.3153	0.3300
100	84.77	75.93	99.07	78.02	64.46	66.18	0.3666	0.3656
120	87.77	80.15	102.07	81.73	68.61	73.37	0.3800	0.3921
140	81.28	83.33	91.20	84.51	63.09	79.28	0.3631	0.4129

TABLE 8. COMPARISON OF MEASURED AND MODELED PROFILES 26 FEB 76 0732

ALT	K.55		K 4.0		K 10.6		LWC	
M	MEAS	MOD	MEAS	MOD	MEAS	MOD	MEAS	MOD
0	23.68	23.68	26.88	26.88	12.07	12.07	0.0572	0.0572
20	33.35	34.64	38.47	37.95	20.26	20.48	0.1131	0.1072
40	46.61	45.55	54.12	48.64	31.46	30.44	0.1908	0.1664
60	59.29	55.48	68.37	58.16	43.11	40.98	0.2644	0.2264
80	67.30	63.94	78.82	66.15	54.19	51.22	0.3172	0.2808
100	67.58	70.82	78.52	72.58	60.66	60.55	0.3537	0.3265
120	70.79	76.23	79.43	77.58	63.10	68.64	0.3890	0.3628

TABLE 9. COMPARISON OF MEASURED AND MODELED PROFILES 26 FEB 76 0824

ALT	K.55		K 4.0		K 10.6		LWC	
M	MEAS	MOD	MEAS	MOD	MEAS	MOD	MEAS	MOD
0	24.86	24.86	26.57	26.57	10.47	10.47	0.0630	0.0630
20	33.75	35.87	38.01	37.63	18.05	18.41	0.1124	0.1147
40	44.94	46.71	51.25	48.35	29.46	28.10	0.1872	0.1745
60	56.38	56.49	65.02	57.91	40.97	38.60	0.2476	0.2340
80	69.50	64.78	81.41	65.95	53.39	48.97	0.3170	0.2874
100	78.14	71.49	90.70	72.41	64.65	58.54	0.3680	0.3318
120	81.28	76.74	81.28	77.46	75.86	66.92	0.3981	0.3670

TABLE 10. COMPARISON OF MEASURED AND MODELED PROFILES 3 MAR 78 2207

ALT	K.55		K 4.0		K 10.6		LWC	
M	MEAS	MOD	MEAS	MOD	MEAS	MOD	MEAS	MOD
0	4.40	4.40	4.48	4.48	1.25	1.25	0.0037	0.0037
20	3.40	8.02	3.24	10.45	0.05	2.83	0.0037	0.0067
40	2.36	17.00	1.93	19.21	0.44	6.90	0.0038	0.0135
60	2.45	27.28	2.04	29.80	0.45	13.46	0.0223	0.0304
80	8.79	38.36	11.35	40.87	2.97	22.22	0.0808	0.0689
100	25.47	49.02	34.57	51.31	11.22	32.37	0.2065	0.1221
120	48.83	58.49	64.45	60.45	25.20	42.91	0.3255	0.1822
140	66.03	66.42	85.26	68.01	37.71	53.02	0.3464	0.2412
160	68.73	72.79	86.75	74.04	44.34	62.13	0.3974	0.2936
180	77.60	77.74	94.04	78.71	56.37	69.98	0.4012	0.3368
200	96.20	81.52	96.08	82.25	58.02	76.52	0.4100	0.3708

TABLE 11. COMPARISON OF MEASURED AND MODELED PROFILES 3 MAR 78 2235

ALT	K .55		K 4.0		K 10.6		LWC	
M	MEAS	MOD	MEAS	MOD	MEAS	MOD	MEAS	MOD
0	5.55	5.55	6.22	6.22	1.35	1.35	0.0133	0.0133
20	6.21	10.72	7.05	13.23	1.65	3.07	0.0138	0.0298
40	8.38	19.58	9.76	22.78	3.08	7.33	0.0347	0.0679
60	18.83	30.21	24.03	33.68	9.67	14.09	0.0727	0.1208
80	42.91	41.28	55.97	44.64	24.73	23.00	0.1798	0.1809
100	66.46	51.68	84.76	54.68	42.29	33.21	0.3082	0.2400
120	78.96	60.75	97.37	63.27	55.02	43.74	0.3947	0.2925
140	89.69	68.25	107.91	70.29	65.86	53.79	0.4660	0.3360
160	101.11	74.23	119.91	75.81	77.86	62.81	0.5484	0.3701
180	108.86	78.86	127.56	80.06	88.24	70.55	0.6218	0.3962
200	113.17	82.36	131.24	83.27	91.48	76.98	0.6843	0.4156

TABLE 12. COMPARISON OF MEASURED AND MODELED PROFILES 3 MAR 78 2309

ALT	K .55		K 4.0		K 10.6		LWC	
M	MEAS	MOD	MEAS	MOD	MEAS	MOD	MEAS	MOD
0	4.10	4.10	4.38	4.38	0.69	0.69	0.0059	0.0059
20	3.45	7.34	3.44	10.28	0.54	1.52	0.0047	0.0116
40	2.96	15.22	2.73	18.99	0.53	3.47	0.0045	0.0254
60	4.38	25.20	4.65	29.55	1.32	8.03	0.0104	0.0667
80	11.76	36.22	14.77	40.63	5.53	15.09	0.0409	0.1117
100	29.33	47.04	38.51	51.09	15.40	24.21	0.1096	0.1713
120	51.71	56.78	67.57	60.26	28.32	34.51	0.1970	0.2310
140	70.74	65.01	89.20	67.86	43.22	45.03	0.2980	0.2848
160	82.41	71.68	100.17	73.92	56.66	54.97	0.3900	0.3297
180	89.02	76.89	106.47	78.61	65.25	63.84	0.4489	0.3654
200	100.79	80.88	118.91	82.18	75.64	71.42	0.5181	0.3926

TABLE 13. COMPARISON OF MEASURED AND MODELED PROFILES 3 MAR 78 2345

ALT	K .55		K 4.0		K 10.6		LWC	
M	MEAS	MOD	MEAS	MOD	MEAS	MOD	MEAS	MOD
0	29.55	29.55	28.14	28.14	8.80	8.80	0.0656	0.0656
20	19.53	40.63	36.68	39.22	8.36	16.16	0.0629	0.1180
40	18.86	51.09	25.67	49.81	8.12	25.48	0.0616	0.1779
60	24.73	60.26	33.37	59.17	11.76	35.87	0.0871	0.2372
80	40.54	67.86	53.22	66.97	26.60	46.35	0.1634	0.2902
100	58.42	73.92	74.07	73.22	45.04	56.17	0.2641	0.3341
120	71.43	78.61	88.19	78.08	53.73	64.88	0.3739	0.3687
140	82.12	82.18	107.77	81.78	61.44	72.29	0.4774	0.3951
160	94.56	84.85	129.07	84.55	75.00	78.40	0.5474	0.4146
180	106.79	86.82	125.16	86.60	87.90	83.32	0.6113	0.4289

TABLE 14. COMPARISON OF MEASURED AND MODELED PROFILES 4 MAR 78 0025

ALT	K .55		K 4.0		K 10.6		LWC	
M	MEAS	MOD	MEAS	MOD	MEAS	MOD	MEAS	MOD
0	30.66	30.66	41.39	41.39	15.85	15.85	0.1163	0.1163
20	32.74	41.72	43.55	51.78	18.03	25.12	0.1315	0.1762
40	31.79	52.08	42.47	60.84	17.10	35.48	0.1249	0.2356
60	30.58	61.09	41.47	68.33	15.41	45.97	0.1180	0.2887
80	36.38	68.53	48.61	74.29	19.58	55.83	0.1418	0.3325
100	49.38	74.45	63.84	78.90	30.04	64.59	0.2139	0.3678
120	65.10	79.02	81.87	82.39	43.84	72.05	0.3094	0.3944
140	79.96	82.48	98.53	85.00	58.87	78.20	0.4156	0.4142
160	89.14	85.07	108.07	86.94	70.13	83.16	0.4960	0.4286
180	92.10	86.99	109.93	88.35	75.70	87.08	0.5343	0.4389
200	91.05	88.39	108.06	89.39	73.18	90.15	0.5311	0.4464

TABLE 15. COMPARISON OF MEASURED AND MODELED PROFILES 4 MAR 78 0158

ALT	K .55		K 4.0		K 10.6		LWC	
M	MEAS	MOD	MEAS	MOD	MEAS	MOD	MEAS	MOD
0	22.82	22.82	30.29	30.29	11.51	11.51	0.0845	0.0845
20	37.60	33.73	49.39	41.36	22.59	19.76	0.1660	0.1409
40	47.93	44.68	62.31	51.75	30.82	29.64	0.2263	0.2014
60	54.04	54.72	69.41	60.82	35.64	40.17	0.2609	0.2588
80	60.89	63.31	77.65	68.31	40.64	50.46	0.2958	0.3082
100	64.46	70.31	81.79	74.27	43.67	59.87	0.3168	0.3486
120	68.61	75.83	86.16	78.89	48.34	68.06	0.3505	0.3799
140	77.68	80.08	96.02	82.38	57.67	74.93	0.4165	0.4034
160	87.52	83.28	106.87	85.00	66.85	80.54	0.4783	0.4207
180	98.20	85.66	118.48	86.93	76.71	85.02	0.5432	0.4333
200	116.35	87.42	128.06	88.35	95.23	88.54	0.6103	0.4424

TABLE 16. COMPARISON OF MEASURED AND MODELED PROFILES 4 MAR 78 0523

ALT	K .55		K 4.0		K 10.6		LWC	
M	MEAS	MOD	MEAS	MOD	MEAS	MOD	MEAS	MOD
0	33.21	33.21	43.47	43.47	19.37	19.37	0.1356	0.1356
20	50.53	44.19	64.12	53.64	33.71	29.20	0.2323	0.1961
40	79.03	54.28	96.63	62.41	60.33	39.72	0.4164	0.2540
60	91.47	62.94	109.48	69.59	74.27	50.03	0.5178	0.3043
80	84.11	70.02	100.71	75.28	68.38	59.49	0.4821	0.3454
100	73.33	75.61	89.06	79.65	58.01	67.74	0.4133	0.3774
120	68.00	79.90	83.43	82.96	52.82	74.67	0.3794	0.4016
140	68.22	83.15	83.86	85.42	52.74	80.32	0.3804	0.4194
160	69.77	85.56	85.74	87.24	53.58	84.58	0.3876	0.4324
180	70.47	87.35	86.63	88.58	53.56	88.40	0.3888	0.4417
200	70.49	88.65	86.63	89.55	53.29	91.17	0.3892	0.4483

TABLE 17. COMPARISON OF MEASURED AND MODELED PROFILES 4 MAR 78 0629

ALT	K .55		K 4.0		K 10.6		LWC	
M	MEAS	MOD	MEAS	MOD	MEAS	MOD	MEAS	MOD
0	38.34	38.34	50.51	50.51	19.39	19.39	0.1369	0.1369
20	36.43	49.00	48.20	59.76	18.10	29.22	0.1281	0.1975
40	39.79	58.47	51.88	67.46	21.48	39.74	0.1515	0.2552
60	45.26	66.41	57.88	73.60	27.01	50.05	0.1897	0.3053
80	47.55	72.78	60.49	78.37	29.28	59.51	0.2055	0.3452
100	46.79	77.74	59.93	82.00	28.13	67.75	0.1979	0.3780
120	44.63	81.52	57.75	84.71	25.80	74.68	0.1821	0.4021
140	43.21	84.35	56.15	86.72	24.53	80.33	0.1735	0.4198
160	42.47	86.46	55.15	88.19	24.07	84.85	0.1705	0.4326
180	43.44	88.00	56.11	89.27	24.94	88.41	0.1672	0.4418

TABLE 18. COMPARISON OF MEASURED AND MODELED PROFILES 4 MAR 78 0759

ALT	K .55		K 4.0		K 10.6		LWC	
M	MEAS	MOD	MEAS	MOD	MEAS	MOD	MEAS	MOD
0	1.48	1.48	0.51	0.51	0.08	0.08	0.0009	0.0009
20	1.38	2.06	0.48	0.89	0.08	0.16	0.0009	0.0013
40	1.43	3.10	0.67	1.73	0.10	0.32	0.0011	0.0020
60	3.40	5.17	3.45	3.86	0.51	0.68	0.0045	0.0033
80	6.11	9.82	7.41	10.09	1.09	1.50	0.0093	0.0060
100	10.10	18.38	12.37	18.75	3.56	3.42	0.0259	0.0118
120	16.50	28.87	20.86	29.27	7.12	7.95	0.0501	0.0260
140	22.91	39.95	30.27	40.35	9.34	14.98	0.0671	0.0617
160	27.72	50.47	36.93	50.84	11.44	24.07	0.0845	0.1130
180	29.50	59.73	38.76	60.05	8.41	34.37	0.0623	0.1727

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